Specification Amendments

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Direct volumetric displays have been created by a number of researchers, such as [Elizabeth Downing et al. A Three-Color, Solid-State, Three-Dimensional Display. Science 273,5279 (Aug. 30, 1996), pp. 1185-118; R. Williams. Volumetric Three Dimensional Display Technology in D. McAllister (Ed.) Stereo Computer Graphics and other True 3D Technologies, 1993; and G. J. Woodgate, D. Ezra, et.al. Observer-tracking Autostereoscopic 3D display systems. Proc. SPIE Vol. 3012, p.187-198, Stereoscopic Displays and Virtual Reality Systems IV, Scott S. Fisher; John O. Merritt; Mark T. Bolas; Eds., all of which are incorporated by reference herein]. One commercial example of such a display is [[[]]Actuality Systems~~: http://actuality-systems.com/, incorporated by reference herein]~~. A volumetric display does not create a true lightfield, since volume elements do not block each other. The effect is of a volumetric collection of glowing points of light, visible from any point of view as a glowing ghostlike image.

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Various physical arrangements could be used to implement this technique. For our first implementation, an approach was used that would allow the greatest flexibility and ability to conduct tests. For the display screen 12, a Digital Light Processor (DLP) micro-

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mirror projector from Texas Instruments ~~[Texas Instruments: http://www.ti.com/dlp, incorporated by reference herein]~~ was used, because DLP projectors handle R,G,B sequentially. This allowed the use of color to encode the three time-sequential phases. A Ferroelectric Liquid Crystal (FLC) element from [[[]]Displaytech~~: http://www.displaytech.com/shutters.html, incorporated by reference herein]~~ to shutter the start/stop time of each temporal phase was used.

a2 cncl.

For the light-blocking shutter, a custom pi-cell liquid crystal 26 screen built to our specifications by [[[]]LXD~~: http://www.lxdinc.com/, incorporated by reference herein]~~ was used, which was driven from power ICs mounted on a custom-made Printed Circuit Board (PCB). To control the sub-frame timings, a Field Programmable Gate Array (FPGA) from [[[]]Xilinx~~: http://www.xilinx.com/, incorporated by reference herein]~~ was used. These were all driven from a Pentium II PC, running OpenGL in Windows NT.

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Figure 12a and Figure 12b, which are computer generated illustrations, show the pi-cell device that was manufactured by [[[]]LXD~~: http://www.lxdinc.com/, incorporated by reference herein]~~. The image to the left shows the size of the screen, the close-up image to the right shows the individual microstripes and edge connectors. The active area is 14"x12",

and the microstripes run vertically, 20 per inch. The microstripe density could easily have exceeded 100 per inch, but the density chosen required to drive only 256 microstripes, and was sufficient for a first prototype. Edge connectors for the even microstripes run along the bottom; edge connectors for the odd microstripes run along the top. Four power chips to maintain the required 40 volts, each with 64 pin-outs were used. Two chips drive the 128 even microstripes from a PCB on the top of the shutter, the other two drive the 128 odd microstripes from a PCB along the bottom. To turn a microstripe transparent, drive it with a 5 volt square wave at 180 Hz. To turn a microstripe opaque, drive it with a 40 volt square wave at 180 Hz.

a3

A ferro-electric liquid crystal 26 (FLC) will switch even faster than will a pi-cell, since it has a natural bias that allows it to be actively driven from the on-state to the off-state and back again. A ferro-electric element can be switched in 70 microseconds. Unfortunately ferro-electric elements are very delicate and expensive to manufacture at large scales, and would therefore be impractical to use as the light shutter. However, at small sizes they are quite practical and robust to work with. A small ferro-electric switch was used over the projector lens, manufactured by Displaytech ~~[Displaytech: http://www.displaytech.com/shutters.html, incorporated by reference herein]~~, to provide a sharper cut-off between the three phases of the shutter sequence. This element is periodically closed between the respective red, green, and blue phases of the DLP projector's cycle. While

the FLC is closed, the pi-cell microstripes transitions (which require about 1.2 ms) are effected.

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The result is two (x,y,z) triplets, one for each eye, at every video frame. A Kalman filter [M. Grewal, A. Andrews, Kalman Filtering: Theory and Practice, Prentice Hall, 1993, incorporated by reference herein] is used to smooth out these results and to interpolate eye position during the intermediate fields. A number of groups are planning commercial deployment of retroreflective-based tracking in some form, including IBM ~~[M. Flickner: http://www.almaden.ibm.com/cs/blueeyes/find.html, incorporated by reference herein]~~. For calibration tests, the DynaSite from Origin Systems ~~[Origin Systems: http://www.orin.com/3dtrack/dyst.htm, incorporated by reference herein]~~ were used, which requires the user to wear a retroreflective dot, but does not block the user's line of sight.